PIV MEASUREMENTS IN WEAKLY BUOYANT GAS JET FLAMES*

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INTRODUCTION

Despite numerous experimental investigations, the characterization of microgravity laminar jet diffusion flames remains incomplete. Measurements to date have included shapes, temperatures, soot properties, radiative emissions and compositions, but full-field quantitative measurements of velocity are lacking (Law and Faeth 1994). Since the differences between normal-gravity and microgravity diffusion flames are fundamentally influenced by changes in velocities, it is imperative that the associated velocity fields be measured in microgravity flames. Velocity measurements in nonbuoyant flames will be helpful both in validating numerical models and in interpreting past microgravity combustion experiments.

Pointwise velocity techniques are inadequate for full-field velocity measurements in microgravity facilities. In contrast, Particle Image Velocimetry (PIV) can capture the entire flow field in less than 1% of the time required with Laser Doppler Velocimetry (LDV). Although PIV is a mature diagnostic for normal-gravity flames (Mungal et al., 1995; Goss et al., 1991), restrictions on size, power and data storage complicate these measurements in microgravity (Kato et al., 1998).

Results from the application of PIV to gas jet flames in normal gravity are presented here. Ethane flames burning at 13, 25 and 50 kPa are considered. These results are presented in more detail in Wernet et al. (2000). The PIV system developed for these measurements recently has been adapted for on-rig use in the NASA Glenn 2.2-second drop tower.

EXPERIMENTAL METHODS

Burner Configuration

The PIV measurements were conducted inside a windowed pressure vessel with optical access for introducing the laser light sheet and imaging the scattered light. The chamber is 53 cm long by 25 cm diameter. A vacuum pump was used to maintain the pressure in the chamber and remove product gases during the tests.

The tests were conducted at pressures of 13-50 kPa. These low pressures were selected to minimize flame flicker and to allow consideration of flames of varying levels of buoyancy.

The burner was a 75 mm long stainless tube with an inside diameter of 1.5 mm. This length ensured fully developed laminar flow at the jet discharge. The burner was placed on the chamber centerline and oriented so that its tip was within the view of the PIV camera. Mass flow controllers regulated the ethane and air streams. Most of the air was unseeded and entered the chamber bottom through a small frit. The remainder of the air was seeded and was supplied via a 22 cm diameter ring of 9.5 mm diameter tubing. The ring was perforated with twenty 1 mm holes and was mounted just above the bottom of the chamber.

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PIV Technique

A dual head mini-Nd:YAG laser operating at 532 nm was used to generate 50 mJ pulses. A 50 mm by 100 μm light sheet was generated using a 25 mm cylindrical and a 300 mm spherical lens.

A 1000x1000 pixel Kodak ES 1.0 camera equipped with a 50 mm Schneider lens (set at f/5.6) was used to record the PIV image data. An interference filter (532±10 nm) was used to attenuate the flame luminosity. The first exposure had a 250 μs integration period to limit the influence of flame luminosity. The second frame was integrated for 33 ms (while the first frame was being read from the sensor), which yielded an image of both the seed particles and the flame. The scale of the images was 53 μm/pixel, corresponding to a magnification of 0.17.

TSI's Insight software and Synchronizer were used to control and synchronize the laser and camera. Image frame pairs were obtained by straddling adjacent frames, allowing acquisition of independent vector maps at 15 Hz. A digitizer was used to acquire image data in 200 image sequences. The present results were obtained by averaging 100 frames, yielding estimated velocity uncertainties of ±1% near the flame centerline and somewhat higher uncertainties elsewhere.

The data were cross-correlation processed using 32x64 pixel subregions with r and z spacings of 16 and 32 pixels, respectively, corresponding to grid point separations of 0.85x1.7 mm in the velocity vector maps. The analysis of the present PIV images uses the correlation software of Wernet (1999) and is discussed in detail in Wernet et al. (2000).

Seeding

The seed particles for the present tests were 2.5 μm silica particles. One seeder was used for the fuel gas and another was used for the air entering the perforated ring. Microgravity rules out traditional seeders such as fluidized or packed beds, which can produce uncontrolled or overseeded conditions in microgravity (Greenberg et al., 1997). Prior work in the microgravity facilities at NASA Glenn demonstrated the viability of orifice-inlet seeders (Greenberg et al., 1997). By introducing gas into the seeder via a small orifice, sufficiently high velocities are generated for controllable particle entrainment.

The most difficult region to seed was the outer edge of the flame, where thermophoresis deflected many particles. Despite low seed concentrations, we were able to obtain velocities in this region.

RESULTS AND DISCUSSION

PIV data were collected at 3 ambient pressures: 13, 25 and 50 kPa. The ethane flow was maintained at 1.9 mg/s for all conditions. The air flow was 160 mg/s for the 25 and 50 kPa cases, but was reduced to 120 mg/s for the 13 kPa case to minimize turbulence in the ambient air.

The flow streamlines computed using the PIV data show that the ambient air in the chamber was disturbed owing to the nonuniformities in the air supply which will be corrected in future work. The measured burner exit velocities were generally higher than expected for fully-developed flow at 300 K, indicating that the burner gas was heated above ambient temperature.

The processed PIV velocity vector map for the 50 kPa flame is shown in Figure 1. The burner location is shown. The flame shapes have been included to show the location and extent of the flame. Streamlines have been determined from the measured velocities and are overlaid on the flow field. The streamline starting points are roughly equally spaced at the upstream boundary. The 50 kPa flame was observed to be slightly flickering.

The flow centerline velocities are plotted as a function of height above the burner in Figure 2. The 25 and 50 kPa flames exhibit centerline velocities which are affected by buoyancy. Only the 50 kPa flame has accelerating flow near its tip.

The PIV system described here has been reassembled on a rig suitable for testing in the 2.2-second drop tower.

ACKNOWLEDGMENTS

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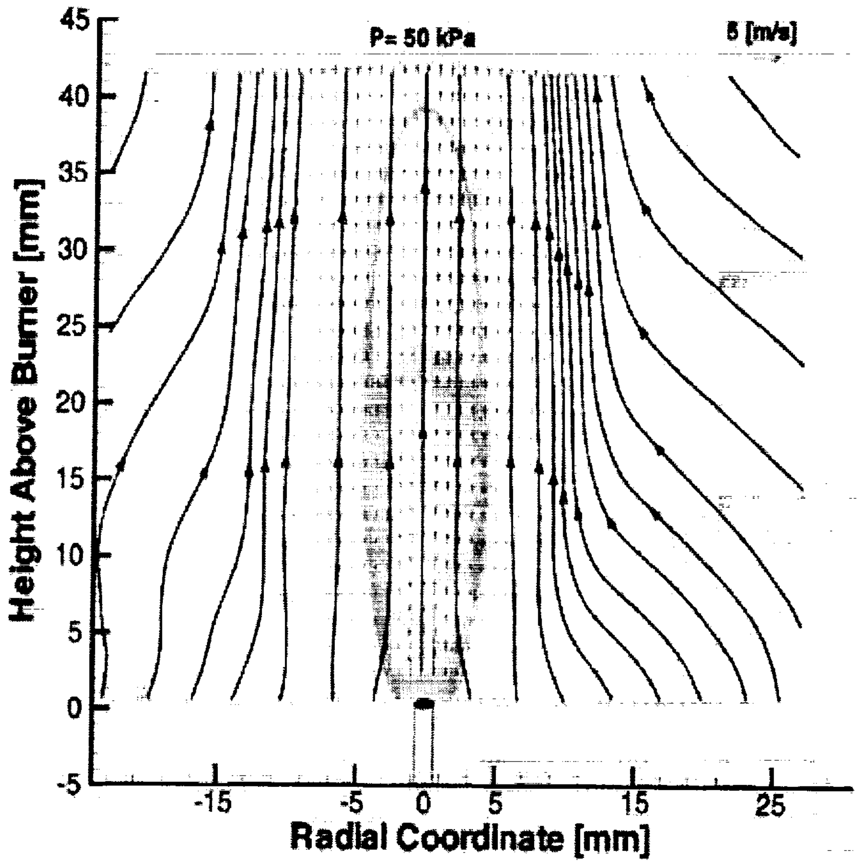

Figure 1. Velocity vectors, streamlines, and flame outline for the 50 kPa flame.

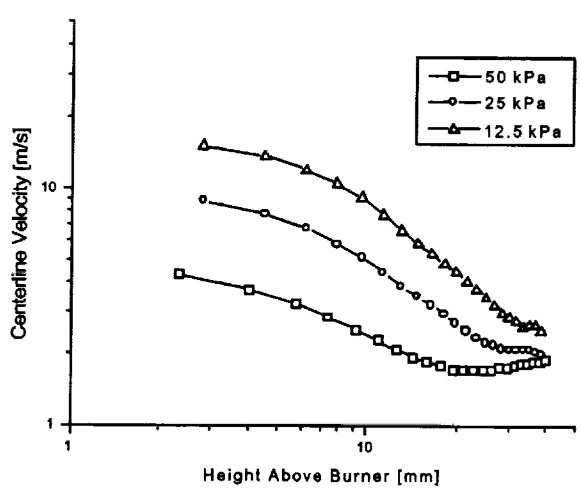

Figure 2. Centerline velocity as a function of height above burner.